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ABSTRACT

In this paper, the ways in which analogies are used in the Energy and the Human Body curriculum will be examined and some preliminary assessments of successes and difficulties will be discussed. Also investigated will be what the first year's study trials suggest about the effective use of analogies in the middle-school classroom. Characteristics of good analogies for middle school students are suggested along with the question: When are analogies the right tool to use in helping students understand science concepts? (Contains 12 references.) (MVL)

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WHEN ARE ANALOGIES THE RIGHT TOOL? A LOOK AT THE STRATEGIC USE OF ANALOGIES IN TEACHING CELLULAR RESPIRATION TO MIDDLE-SCHOOL STUDENTS[1]

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TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

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Analogies have been seen as both a means of natural learning and an important teaching method (Gentner, 1989, Hatano and Inagaki, 1988). In a science education context, analogies are comparisons between something familiar to students (the base) and an unfamiliar area in science that teachers want students to understand (the target) (Glynn, 1991). Analogies may serve a number of functions in helping students learn science. Functions that have been hypothesized include: 1) the base serves to help students construct an imperfect preliminary model (M1) which is later modified by students to approximate the scientists' model (Clement and Steinberg, in press); 2) knowledge may be transferred or extended from the familiar base to the unfamiliar target so that students do not have to construct the entire target (Clement, 1993; Gentner,1989; Minstrell, 1982); 3) the base and target are both examples of a larger pattern or class of knowledge and help to illustrate this pattern (Gentner, 1989); 4) analogies may help activate visual imagery (Duit, 1990; Johsua and Dupin, 1987; Yang and Wedman, 1993); 5) analogies may be memorable and thus increase the memorability of new knowledge (Wong, 1993); 6) analogies may provide affective and motivational support for learning (Gowin, 1993 in Duit,1990); and 7) student-generated analogies may serve process goals such as the activation of

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creativity and imagination and may help students generate as well as evaluate hypotheses (Dagher, 1994; Wong, 1993).

The *Energy in the Human Body* curriculum uses analogies and other tools to help middle-school students understand cellular respiration (Rea-Ramirez, 1998). Cellular respiration is the biochemical system in nearly all living things in which the chemical energy contained in the glucose molecule is transferred to molecules which serve to store and transport energy so it can be used in the cell's functions. The curriculum is different from other middle-school life science curricula in that it is:

- Research-based, having been developed after a set of individual and small-group tutoring interviews.
- Integrated, in that cellular processes are connected to the body systems that assimilate and transport food, oxygen and the waste products of cellular respiration. The entire curriculum forms a coherent "story" about how energy is used in the body.
- Strategic, in that multiple teaching and learning tools are used to help students build understanding, and in that these tools are employed as deemed appropriate for specific learning goals. Teaching and learning tools used in the curriculum include analogies, cooperative/small-group work, "learning by drawing," dissonance-producing questions, and recall of students' "daily life" experiences. The general pedagogical approach in the curriculum is model generation, evaluation, and modification (GEM) cycles, with the above tools used to assist students in the process of developing and revising mental models (Rea-Ramirez, 1998).

In this paper, we will examine the ways in which analogies are used in the *Energy and the Human Body* curriculum and discuss some preliminary assessments of successes and difficulties. In addition, we will look at what our first year's trials suggest about the effective use of analogies in the middle-school classroom. We will also suggest some characteristics "good" analogies for middle-school students. Lastly, we'll explore the question: When are analogies the "right tool" to use in helping students understand science concepts?

The Use of Analogies in the *Energy in the Human Body* Curriculum

The *Energy in the Human Body* curriculum is used to teach middle-schoolers concepts and knowledge that are largely unfamiliar to them. The curriculum has the ambitious content goals of teaching four body systems, cell structure and function concepts, and energy concepts that are related to human physiology. The subunits are taught in interconnected fashion, and for understanding rather than memorization. The teaching approach is also student-active, in that many if not most of the ideas used in constructing knowledge come from students themselves (Rea-Ramirez, 1998).

The curriculum was developed after a series of tutoring interviews and a "trial run" of the teaching approach with four middle-school students (Rea-Ramirez ,1998). The ideas in this paper are based on observations made during the first year's trial in three middle school classrooms, in which both successes and challenges in the use of analogies were seen. Our observations were used to criticize and revise the curriculum for a second year of testing. In this paper we reflect on patterns in this formative improvement process in order to form hypotheses about purposes and techniques for using analogies in instruction.

Table 1 shows examples of analogies used in the curriculum. The analogies used vary both in complexity and in purpose. Complex analogies such as the school analogy have a number

of elements that correspond or "map" between base and target. Simple analogies, such as the "ear of corn" analogy, have only a few elements which map. These two analogies also vary in purpose, with the school analogy being designed to help students understand the functions of cell parts and the relations among them, and the ear of corn analogy being designed simply to generate a visual or geometric model which helps students understand how cells are arranged.

The analogies described in Table 1 are intended to assist students in constructing content pieces that are of critical importance in understanding the "story" of cellular respiration. In our first year of classroom curriculum trial, they were explicitly identified as analogies by the teacher and in the manual used by students. In addition, the manual asked teachers to "map" the analogies, drawing lines from each feature of the base to the corresponding feature of the target. The processing of these analogies took a significant amount of time, from approximately 20 minutes for the ear of corn analogy to an entire class period or more for the school analogy.

In addition to the formal, structured analogies described above, we recognize a second type of way in which analogies are used in our trial classrooms. We have found that both students and teachers use our analogies informally, to illustrate points or explain their ideas to each other. Some students and teachers also engage in the spontaneous use of analogies and metaphors that they have generated themselves, with such use tending to increase as the curriculum progresses. Some examples are as follows. In the small group trial that began this project, one student referred to red blood cells as "like a UPS truck," in that red blood cells drop off oxygen to and pick up carbon dioxide from other cells in the same way that a delivery truck might drop off one package at a house and pick up another. A second student, looking at a model of lung structure, described it as "like a tree." In the first year's classroom trial, a student

Table 1

Examples of analogies used in the "Energy in the Human Body" curriculum

Analogy	Mappable elements	Complexity	Purpose/function
Ear of corn	Arrangement of kernels is like arrangement of cells - both are patterned with little space in between	Simple	Visual/geometric
School analogy	The functions of some school parts are similar to the functions of some cell parts	Complex	Functional
Fire analogy	Fire consumes O_2 and fuel, releases energy CO_2 and water. Mitochondria obtain energy from glucose using O_2, with CO_2 and water as wastes.	Complex	Functional
River delta analogy	A river branches into many smaller branches, blood vessels branch into smaller vessels after leaving the heart	Simple	Visual/geometric
Water pipes analogy	Branching water pipes in a city bring water to houses., blood reaches cells through vessels	Simple	Functional and visual/geometric
Grape analogy	The arrangement of grapes and their stems is similar to the arrangement of alveoli and bronchial tubes in the lungs	Simple	Visual/geometric

described the valves in veins as being like "lobster traps," in that passage or movement occurs in only one direction.

We recognize a distinction between the ways the formal analogies that are structured into the curriculum are presented and the spontaneous way in which analogies and metaphors are used in classroom dialogue. The former are presented in a structured way because of their central role in students' construction of understanding. Our formal analogies are also sufficiently complex as to require careful explication. Informal student and teacher use of metaphors and analogies, on the other hand, generally seems to be for the purpose of illustrating one or a few simple points. Elaborate mapping and explication may not be needed in such cases.

Observations and Reflections on the First Year of Classroom Trials

In the first year's trials of the curriculum, we found that nearly all students were able to map corresponding elements of the base and the target correctly by drawing lines between drawings of the two. We also found that many, although not all, students, exhibited understanding of the purpose of analogies by generating appropriate analogies on their own when asked to. In addition, we noted spontaneous generation of analogies by students during class discussions. Teachers were also observed to invent analogies and to use them as teaching tools.

We also noted some problems with classroom use of analogies. First, we found that students sometimes expressed functional analogies visually. For example, when students drew cells they often drew images of food instead of mitochondria. This confusion may have resulted when students mapped the visual rather than the functional aspects of food onto mitochondria. Second, we found instances in which students "overmapped" analogies, attempting to transfer elements of the base to the target that were inappropriate. We also noted that one of the teachers

had trouble helping students understand the process of mapping analogies. These problems led us to believe that students and teachers needed more explicit instruction and support in processing analogies than we had provided.

Analogies are now presented to students and teachers with the following types of instruction and support:

- The teachers' manual includes an introductory section that explains the pedagogical basis for the use of analogies and gives teachers a set of steps to use in introducing analogies. It also discusses potential pitfalls in using analogies in the classroom.
- The teachers' manual has the student manual embedded within it. Boxes surrounding the student manual give teachers tips for presenting the analogies and prompt them to reflect on the pedagogical basis for using analogies.
- Students are asked to draw and map base and target as individuals, rather than in small groups. Students are then asked to discuss the information implicit in their drawings both in small groups and as a class. This requires students to process their understandings thoroughly, and give them a chance to learn from other students.
- Students are given tables in which they enter elements of base and target that do and do not correspond when mapping complex analogies such as the school and fire analogies.
- Teachers and students are guided explicitly as to which elements of the base to examine in order to understand the target. For example, in the ear of corn analogy students are told to look at the pattern or arrangement of the kernels and not at their hardness and colors.
- The students' manual includes "check-ups" or quizzes in which students are asked to reiterate understandings gained through analogies.

- The students' manual also contains opportunities for students to reflect on analogies metacognitively.

Analogies and Middle-School Students

Our experiences suggest that analogies can be used as learning tools by middle-school students. We have found particular success with the school analogy, which is familiar to students and which helps them understand otherwise fairly inaccessible material. Students recall the school analogy easily and use it spontaneously in written work and oral discussions. The school analogy also gives the students access to a functional understanding of the cell and its parts. This makes it less likely that students will learn cell parts in a meaningless "rote" fashion and provides a conceptual foundation for understanding mitochondrial function. We have also seen students correct their models when prompted to remember an analogy. For example, several students who were drawing cells in tissue as widely dispersed rather than close together were asked what they learned from the ear of corn analogy. The students immediately revised their drawings to show cells as contiguous. This suggests that students have retained these analogies and can use them to correct and/or reinforce understandings.

Even these analogies, however, were not understood by all students in trials in which they were not mapped and explained explicitly. In trials in which these analogies appeared to be used successfully, teachers drew connections between features of the base and corresponding features of the targets. In addition, analogies in which the base was not familiar to the students appeared to be used less successfully by students. For example, an analogy in which a party popper was compared to energy-rich ATP molecules seemed to have confused a number of students, who were unable to say what they learned from the analogy. Mapping of this analogy was difficult for

both teachers and students, and we failed to include a step in which students became familiar with the elements of the base before developing the analogy.

While we cannot draw specific conclusions from our research to date, we do believe we have evidence to suggest that the careful, elaborate processing we have introduced with our formal analogies in the second year of our trial is needed for understanding. We might therefore suggest that a good analogy for middle-school students is one which is either already familiar to them or one which they become familiar with through careful and guided examination. In addition, we suggest that because correspondences between base and target must be understood, a high proportion of clearly "mappable" elements is a feature that would define a "good" analogy.

When are Analogies the "Right Tool?"

We consider analogies to be useful to students who are learning about the human body because they help students build visualizable mental models that are transitions to our "target" models - models that are like scientists' understandings. As shown in Table 1, we believe many serve to provide the foundation for new visual imagery, and that others provide a basis for a more conceptual functional understanding. We have also observed that students tend to find analogies engaging and approach them actively, suggesting that they may serve motivational and process goal functions. In addition, because analogies must be thought through to be understood at all, we suggest that analogies encourage active student construction even in students who are not accustomed to thinking actively in school science.

We recognize that, if they are to be understood by students, analogies, especially complex ones, require highly-structured and intensive processing. We therefore reserve analogies for concepts that are not accessible to students through demonstrations or experience and that can

not be readily constructed by students through discussion and inference. We use analogies to introduce the target concepts in Table 1 - cell arrangement, cell parts, mitochondrial inputs and outputs, blood vessel and lung structure – because they can not easily be built by students themselves. In contrast, through logic and experience, students are rather easily able to construct models in teacher-supported discussion such as the "two tube" model of the throat, in which stomach and lungs are connected to the mouth by separate tubes, without the more directive guidance of analogies. With some prompting by the teacher, students have access to such experiences as choking, burping, and swallowing, which they can use as "clues" when they try to infer their own internal structure. They are also able, with teacher support, to produce ideas such as the inference that if they did not have two tubes, they would be likely to get air in their stomachs and food in their lungs. The target concepts that are taught with analogies are unlike the "two tube" concept in that they are not easily understood by students accessing their own experiences.

The use of analogies is also reserved for important concepts, concepts that are prerequisites to further learning. The ear of corn analogy is a case in point. Preliminary research suggested that some students see body cells as having no particular arrangement, as being loosely-packed and not contiguous (Rea-Ramirez, 1998). We deem the understanding that cells are, on the contrary, arranged contiguously, with little intercellular space, to be quite important. Students will, later in the curriculum, be expected to be able to develop understandings of oxygen and carbon dioxide transfer between cells and the blood in capillaries. In order to construct the correct model of the capillary's proximity to the cell, students must have a model in which cells are contiguous. We therefore consider the ear of corn analogy to serve the important content goal of helping students understand how cells are arranged in the body.

Lastly, we have developed criteria that help us evaluate the effectiveness of analogies. As discussed above, one criterion of effectiveness is familiarity and/or accessibility of the base. The ear of corn analogy, for example, is made accessible to students by giving them an actual ear of corn to look at, hold, and draw. The fire analogy to mitochondrial respiration is explored by lighting a candle in a jar, then covering the jar until the flame dies. This demonstrates to students that oxygen is needed for combustion. A second criterion of effectiveness is a high ratio of mappable to non-mappable elements. The fire analogy, for example, maps almost completely to respiration in mitochondria, and the most important exception - the fact that chemical energy released in the cell is captured and used rather than being converted to heat and light - is instructive.

Summary and Conclusions

Analogies are one of a number of tools used in the *Energy and the Human Body* curriculum. In this paper we have we reflected on patterns in our observations of strengths and weaknesses in analogy use in our first round of classroom trials. We have used these reflections to develop hypotheses about appropriate general purposes and techniques for using analogies in instruction. These hypotheses should be subjected to evaluation and improvement in further research. We have come to use analogies in areas of the curriculum which students can not build themselves through logic or experience, such as cell arrangement and mitochondrial inputs and outputs. We believe that the processing students use in examining and understanding the analogies included in the curriculum is active, in that students are asked to examine and reflect on each analogy. We give preference, however, to starting from students' own models when they are available, and use analogies where preliminary research indicates that a concept can not be readily developed by students from their own experiences.

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